Dynamical and chemical contributions to variability in Microwave Limb Sounder Arctic stratospheric column ozone

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Abstract. Analyses of column ozone above 100 hPa (Col100) derived from UARS Microwave Limb Sounder data in Feb/Mar 1992–1998 show that about half of the interannual variability in Col100 in the lower stratospheric vortex in Feb/early Mar results from interannual variability in chemical loss; most of the remainder results from interannual variability in day-to-day dynamical motions. Most of the interannual variability in minimum and maximum high-latitude Col100 is reproduced in dynamical models, emphasizing the dominance of dynamical effects in producing column ozone extrema. The amount of day-to-day variability in dynamical models is similar to that in MLS Col100.

Column Ozone from MLS and Dynamical Models

Many studies demonstrate a strong relationship between Arctic column ozone and dynamical variations [e.g., *Hood et al.*, 2001, and references therein]. Observed decreasing trends in Total Ozone Mapping Spectrometer (TOMS) column ozone in northern hemisphere (NH) high latitudes in Mar in the 1990s [e.g., *Newman et al.*, 1997] are often viewed as evidence of Arctic chemical ozone loss. However, decreasing trends would be seen even in the absence of chemical loss because of the decreasing trend in lower stratospheric temperature [e.g., *Fioletov et al.*, 1997]. There is large interannual variability in column ozone, and much higher ozone was seen in recent unusually warm years [e.g., *Andersen and Knudsen*, 2002]. Variability in high-latitude column ozone, both interannual and intraseasonal, is expected to arise from a combination of dynamical and chemical effects, since lower temperatures are associated with lower column ozone via both dynamical and chemical processes. *Chipperfield and Jones* [1999] showed chemical transport model simulations during the 1990s, in which dynamical variations dominated interannual variability in high-latitude (63-90°N, both vortex and extra-vortex) column ozone.

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However, *Andersen and Knudsen* [2002] estimated from analyses of observations that interannual variability in vortex chemical loss could account for up to ∼75% of the interannual variability in high latitude ozone (again, for 63-90°N). Here, we examine a slightly different question: what are the relative roles of chemical loss and dynamical processes in day-to-day and interannual variability in column ozone in the Arctic vortex?

Column ozone above 100 hPa (Col100) is calculated from version 5 UARS Microwave Limb Sounder (MLS) data [*Livesey et al.*, 2002] by integrating the retrieved abundances over the MLS retrieval grid (6 points per decade change in pressure). Tropopause pressures range from ∼120 to 300 hPa in NH winter, so Col100 represents most, but not all, of the stratospheric column. Comparison of Col100 with TOMS total column (not shown) shows similar morphology and day-to-day evolution [e.g., *Froidevaux et al.*, 1994]. MLS observed ozone in the NH stratosphere in late winter (Feb/Mar) 1992–1998; *Manney et al.* [2002] used these and early winter MLS ozone observations with a Lagrangian transport (LT) model [e.g., *Manney et al.*, 1996, and references therein] to estimate ozone loss on isentropic (θ) surfaces from 385–840 K. We use Col100 from MLS, the LT model, and a simple dynamical model that reconstructs column ozone from equivalent latitude (EqL, the latitude that would enclose the same area between it and the pole as a given potential vorticity (PV) contour)/θ "climatologies" to estimate the relative roles of dynamical and chemical effects in variability in Col100 during these seven late winters.

Fig. 1 shows MLS Col100 averaged over 14–28 Feb, for 1992–1998. This includes three days with good MLS data in 1995, two in 1998, and more in the other years. The lower stratospheric vortex position and cold regions are also shown. Large interannual variability is seen in Col100, temperature, and the relative positions of the low column ozone/cold regions and the vortex. Low Col100 is colocated with low temperature and is often not well correlated with the vortex. Deep, localized, low-Col100 regions are seen in 1993, 1998, and particularly 1996; during these periods, there was a high, cold tropopause extending from the subtropics under the low column ozone region (not shown), characteristic of conditions when deep, localized ozone minima (miniholes) form [e.g., *Hood et al.*, 2001; *Weber et al.*, 2002, and references therein].

Orsolini et al. [2001] showed that column ozone reconstructed from trajectory-modeled high-resolution profiles initialized with MLS EqL/θ ozone for the 1997-1998 winter reproduced most observed day-to-day variations. *Allen and Nakamura* [2002] reconstructed column ozone during a deep minihole using data from several solar occultation instruments combined by mapping versus a tracer EqL, and obtained good agreement with observed values. We use a similar idealized model (the "EqL" model): we assume the same distribution of ozone mixing ratios in EqL/θ space in each year – i.e., that large scale, winterlong transport processes are the same in each winter. We reconstruct 3D ozone distributions by mapping an EqL/θ "climatology" into physical space using daily PV and temperature fields; Col100 is calculated from this as it was from MLS data. The only variations are in the shape of the PV field and the pressure of the isentropes, so the EqL model Col100 reflects only variations in morphology related to the shape of the PV field (including, possibly, poleward advection of low PV, low ozone air during minihole events), and those produced by adiabatic motions of the isentropes. Fig. 2 shows 14–28 Feb averages constructed using a climatology based on EqL/θ averages of all MLS data in 10-day bins throughout the winter [*Manney et al.*, 2002]. A reconstruction based on MLS data from the warm 1997-98 winter (with little ozone loss) shows slightly more interannual variability, with similar lows, but larger maximum values. The considerable interannual differences seen here indicate that adiabatic motion of the isentropes and the shape of the PV field are significant factors contributing to interannual variability in Col100.

Col100 was calculated similarly from LT model [*Manney et al.*, 2002]. LT calculations were done both for Feb/Mar (estimating ozone loss during late winter), and for "extended" runs [*Manney et al.*, 2002] giving an estimate of all, or nearly all, chemical ozone loss through the calculations' ending date. 14-28 Feb averages from the "extended" runs (Fig. 3) show the LT model predictions of column ozone in absence of chemical loss for late Feb. While these show values substantially higher than observed by MLS (Fig. 1) in most years, considerable interannual variability is still evident.

Dynamical and Chemical Variability in MLS Column Ozone

Fig. 4 shows minimum, maximum and average Col100 from MLS and the dynamical models, for the 1992-1998 late winters, in the 465 K vortex region (vortex defined by 1.2 $\times 10^{-4}$s^{-1} scaled PV (sPV) contour, white overlay in Figs. 1-3). Minimum values from the LT model for 14-21 Feb 1996 are suspect because that period was cold enough that the lowest LT model isentrope, 385 K, was above 100 hPa at a few points, which were filled by extrapolation/interpolation of surrounding values; the extended LT run for 1998 is also not thought to be reliable, as the midwinter LT run it was based on was longer than LT calculations are expected to be accurate [*Manney et al.*, 2002]. Both EqL and LT models show as much interannual variability as MLS in the maximum, and nearly as much in the minimum, but only $\sim$1/2 the variability in the average over most of the period ($\sim$3/4 near the beginning). Day-to-day variability in individual years is comparable in MLS and the dynamical models. An increasing trend in LT model values with respect to MLS (except in the warm 1992 and 1998 late winters) indicates ongoing chemical loss. Deep minihole events occurred near 20 Feb and 3 Mar 1996 [e.g., *Weber et al.*, 2002; *Manney et al.*, 1996]. During these, the EqL model - and the LT models when minima are reliable - show changes as large as those in MLS, demonstrating the dominance of dynamical processes in minihole formation, consistent with previous studies [e.g., *Hood et al.*, 2001; *Allen and Nakamura*, 2002]. Minima in the EqL model on 20-21 Feb 1996 are $\sim$30 DU higher than MLS, and $\sim$25-40 DU higher on 29 Feb–3 Mar; LT model minima are $\sim$30 DU higher than MLS in the extended run and $\sim$20 DU in the late winter run. This suggests that chemical loss (rather than interannual variability in large-scale transport which would make the EqL model values differ significantly from the LT model values) is the major reason for lower MLS than dynamical model values.

Interannual variability in 14–28 Feb vortex ozone from MLS and each dynamical model is shown in Fig. 5 with 46 hPa temperatures (which do not always reflect the overall relative "coldness" of the winters). This is near the beginning of the late-winter LT runs (green lines) in the first few years, so for 1992 and 1993 those lines are still close to MLS. The close correlation of temperature with EqL model results reflects the dependence of that model on motion of the isentropes [***(the correspondence in minima is not as strong in 1994 and 1997 when the vortex and cold region were pole-centered and miniholes were not observed)***DELETE???].

The difference between the extended LT model (blue) and MLS (black) Col100 gives an estimate of chemical loss in the vortex in late Feb. The amount of chemical loss estimated for the minimum, average, and maximum in 1996 (the year with most ozone loss, and a time with repeated minihole events) is $\sim$20, 40, and 70 DU, respectively. In the cold regions, especially when miniholes occur, the isentropes are lifted and separated, while in warm regions they are lowered and compressed. This results in a smaller change in column ozone in cold regions than in warm regions for the same change in mixing ratio. This effect may be amplified if column loss is estimated from loss calculated in an isentropic layer (as is done in many studies), as those calculations may exclude changes underneath the lowest isentropic layer in the cold region. This has important implications for estimating column ozone loss in the vortex, especially from datasets with sparse or nonuniform coverage - if sampling is concentrated in warm (cold) regions, we may over (under)estimate vortex-average loss, and the degree to which we do so will vary interannually with the relative positions of the vortex, cold region, and sampling.

Interannual variability in minimum vortex Col100 is ∼60 DU for MLS, and ∼40 DU for LT and EqL models. That in the maximum is ∼40 DU, 35 DU, and 50 DU for MLS, EqL model, and LT model, respectively. Thus dynamical effects explain most, or all, of this variability. In the average, however, the MLS data show ∼45 DU difference between the years, and the dynamical models ∼20-25 DU. Interannual variability in chemical ozone loss thus accounts for about half of the interannual variability seen by MLS in vortex Col100 in late Feb.

Summary

MLS column ozone above 100 hPa is examined in the NH late winters 1992–1998 to assess the relative effects of chemical and dynamical processes on its variability. About half of the interannual variability in stratospheric column ozone averaged in the lower stratospheric vortex in Feb/early Mar is related to interannual variability in chemical loss, in rough agreement with other studies [e.g., *Andersen and Knudsen*, 2002, M. Rex et al., "The Relative Importance of Chemical versus Dynamical Processes for the Springtime Total Ozone Column in the Arctic", in preparation]. Most of the remaining interannual variability is related to variability in the adiabatic motion of the isentropes and in short timescale transport associated with dynamical variations. This does not imply that chemistry is important in determining the morphology of column ozone (the continuing dominance of dynamical effects is apparent in Figs. 1-3), or that chemical loss has a majority impact on column amounts - only that interannual variability is much larger than would be expected without chemical loss. Day-to-day variability in individual winters is of similar magnitude in MLS data and the dynamical models, indicating the dominance of dynamical effects in producing short-term changes.

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Figure Captions

Figure 1. 14–28 Feb MLS Col100 (DU) maps for 1992–1998, with 465 K PV in vortex edge region (white contour), and 205, 200, 195, and 190 K 46 hPa temperatures (black, outer to inner, 205 K contour appears on all maps) from UK Met Office data. Projection is orthographic, with 0°E at the bottom and 90°E to the right; dashed circles are 30° and 90°N.

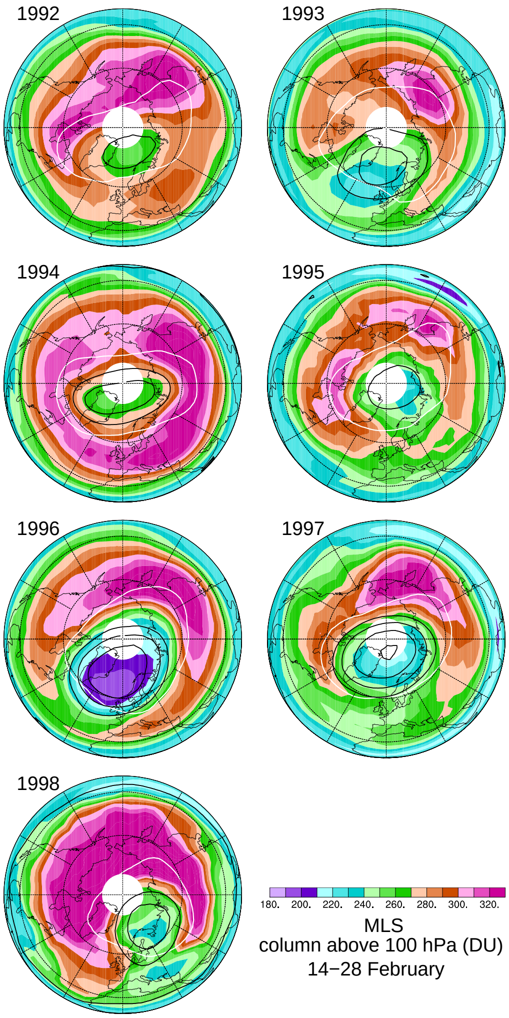
Figure 2. 14–28 Feb Col100 (DU) from EqL model (see text), in 1992–1998. Layout is as in Fig. 1.

Figure 3. 14–28 Feb Col100 (DU) from extended LT model (see text), in 1992–1998. Layout is as in Fig. 1.

Figure 4. (Top to bottom) Maximum, average, and minimum Col100 from (left to right) MLS, EqL model, late winter LT model, and extended LT model, during late winter 1992–1998, averaged within the 465 K vortex.

Figure 5. 14–28 Feb averages of daily (top to bottom) maximum, average, and minimum Col100 in the 465-K vortex, for (black) MLS data, (grey) EqL model, (green) LT model late winter runs, and (blue) LT model extended runs. Magenta line shows Met Office 46 hPa temperatures.

Figures



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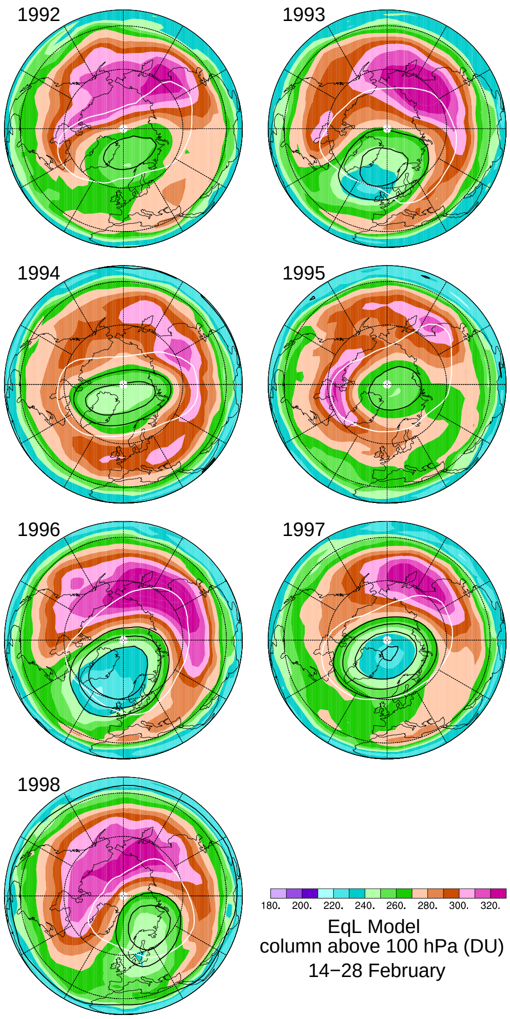

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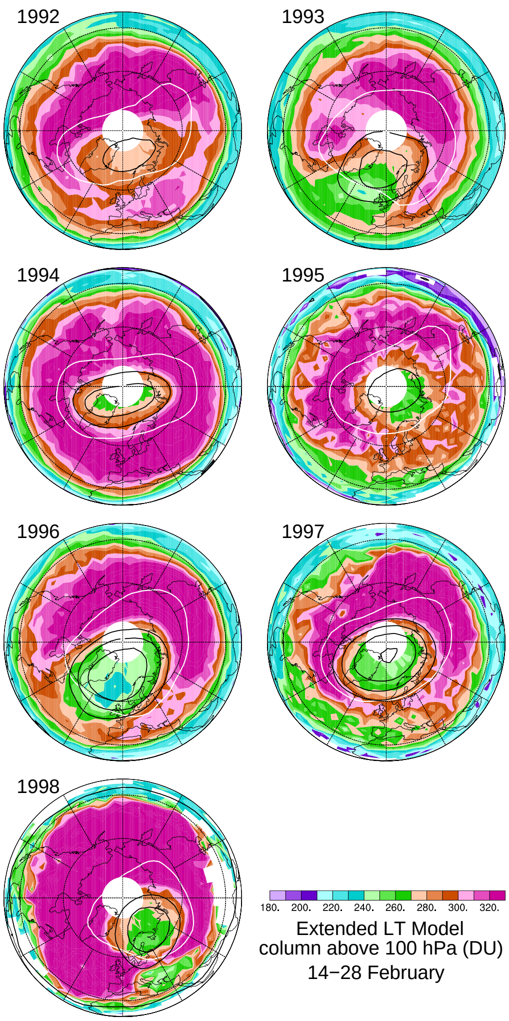

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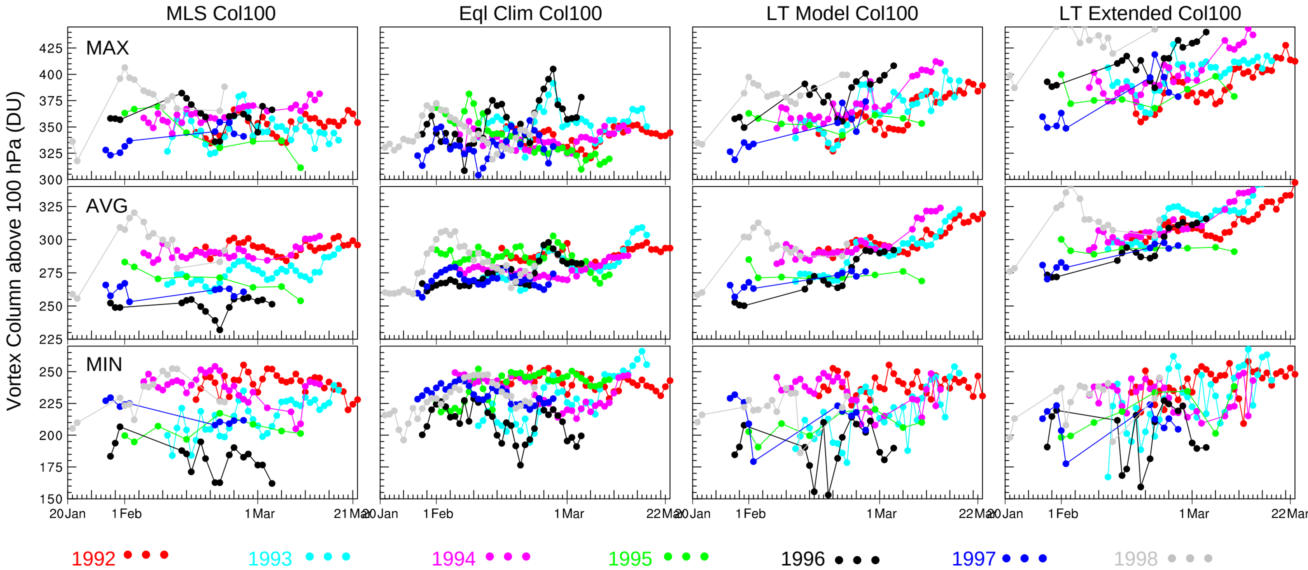

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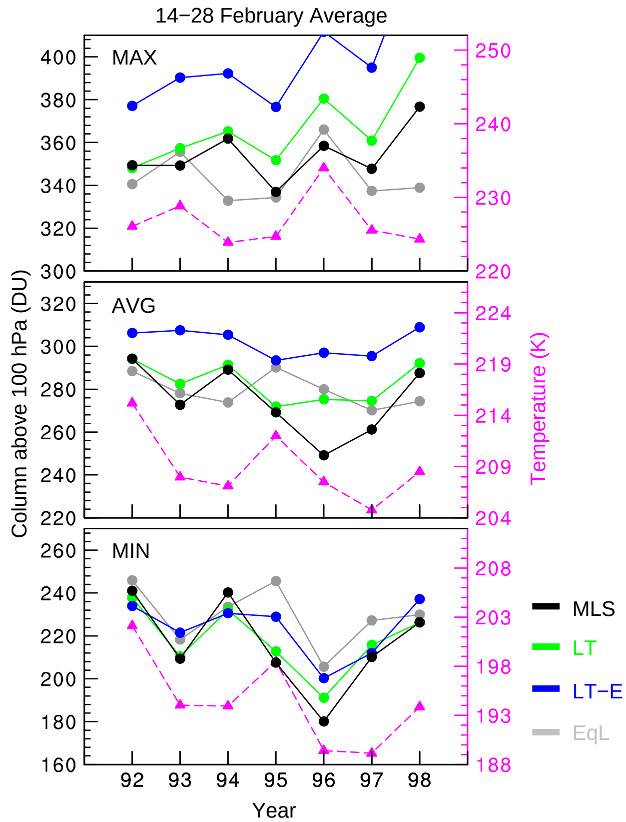

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